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Some physical, mechanical and chemical properties of tomato fruit related to mechanical damage and bruising models

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ABSTRACT: Impact phenomena is one of the important issues related to many of agricultural processes. It can be also considered as common reasons of mechanical damages exerted to the agricultural products occurring in some agricultural operations including; harvesting, handling and processing. Tomato quality is reduced by the bruising damage. There is some parameters cause mechanical damage which should be known consequently can be given useful recommendations. Bruising models may be able to help designers, producers and sellers to reduce such damages. Since machinery play a key role in mechanized operations, it is necessary to optimize the production chain. In order to obtain these aims, the bruising models are essential. To establish these models, the first step is determination the model parameters including: some physical, chemical and mechanical parameters. To gain some essential parameters, the impact was simulated by the manufactured pendulum. The tomatoes were impacted one, two and three times at three levels of energy 0.125, 0.25 and 0.5 J to study the tomato texture behavior. The obtained results showed that by increasing the impact energy levels, the contact peak force increased. The mentioned procedure was similar to the Elast (Contact peak force/contact time) parameter. Also, the restitution coefficient values were the highest for medium impacts and the lowest for lowest impacts. The obtained results can be used to determine the best bruising model for predicting bruising and improving the related machines.

Keywords: Impact, bruising models, tomato, mechanical properties.

INTRODUCTION

Tomato is commercially important vegetable throughout the world both for the fresh fruit market and food industries. It is grown in a wide range of climates in the field, and even under protection in plastic greenhouses and heated glass houses (Atherton and Rudich, 1986, Adedeji, Taiwo *et al.,* 2006). Apart from its characteristics flavor and aroma, it is also a good source of vitamins (A and C) and minerals (Akanbi and Oludemi, 2004). Tomato is consumed in quite large quantities: directly as salads, cooked into soups or processed into juice, ketchup, whole- peeled tomato and paste (Adedeji, Taiwo *et al.,* 2006). In some cases tomatoes are picked at a mature red stage when they are almost suitable for fresh market.

Most mechanical injury of fruit is caused by mechanical impact that occurs during harvesting, handling and transportation. The fruit and vegetable industry suffers considerable economic losses due to bruising and post-harvest physical injuries are common in tomatoes even when those are handled with care (Michael Van Zeebroeck, Tijskens *et al.,* 2003). The amount of losses in Iranian tomato production was about 35 percent (Shadan, 2006); it shows that the condition for this product is very crucial, so it seems to be some special studies should be conducted to reduce such losses. Reducing these defects can also increase food safety level by decreasing the potential for microbial infestation. The aesthetic, trimming and disposal problems associated with these defects can also be reduced by decreasing damage (Baritelle and Hyde, 2001). To diminish the amount of mentioned damages, fruits and vegetables must be carefully handled and distributed. The distribution chain in Iran is so weak and standardization did not keep out. Much research should be focused on the results of the mechanization of tomato harvest and grading with respect to different sorts of mechanical damage. The bruise susceptibility of fruit and vegetables is a measure for the response to external loading and depends on the number of elements such as variety, texture, maturity, mass, firmness, temperature, size, shape, volume, surface area, density, porosity, color and appearance are some of the physical characteristics which are important in many problems associated with the design of a specific machine or analysis of the behavior of the product in handling of the material (Mohsenin, 1986).

Mechanical damage to agricultural products which occurs in harvesting, handling, sorting, grading and transportation cause insects, fungi attack and loss quality of the final product. Some important mechanical properties which contribute in the mechanical damage are rebound coefficient, toughness, stiffness, radius of curvature penetration maximum force into flesh, maximum penetration force and the depth of penetration and acoustic firmness. The textural quality of tomatoes is influenced by flesh firmness. The first step to overcome to this problem is determination of some physical, chemical and mechanical properties (Sargent, Brecht *et al.,* 1992, Desmet, Lammertyn *et al.,* 2002, Goliáš, Bejcek *et al.,* 2003, Michael Van Zeebroeck, Tijskens *et al.*, 2003, Batu, 2004, Van linden, De Ketelaere *et al.,* 2006, Schouten, Huijben *et al.,* 2007, Michael Van Zeebroeck, Darius *et al.*, 2007, Lien, Ay *et al.*, 2009, Milczarek, Saltveit *et al.*, 2009, Li, Li *et al.*, 2011, Li, 2013, Li, Lv *et al.*, 2015).

The most important parameters indicating tomato quality, firmness and color, are related to ripening and shelf life. Firmness indicates maturity, freshness, bruising and internal voids or damage. Fruit color has a strong effect on consumer perception of quality and is an acceptable maturity index for many fruits such as tomatoes (Edan, Pasternak *et al.,* 1997).

The specific objectives of this study are to determine some physical, chemical and mechanical properties of tomato and obtaining mechanical parameters which will contribute in tomato mechanization and establishing bruising models to reduce mechanical damage by improving those machines in the production lines.

Notation

L: Length of Fruit, mm	R^*: radius of curvature ,mm
W: width of fruit, mm	S_g: specific gravity
T: Thickness of fruit, mm	Mwb: Moisture content (wet base), (%)
M: mass, gr	PF: contact peak force, N
V: volume, cm^3	t: contact time, s
ϕ : sphericity (%)	EL: Elast, N/S
Da: arithmetic mean diameter, mm	R_c: restitution coefficient, dimensionless
Dg: geometric mean diameter, mm	S: acoustic firmness, $10^6 gr^2 Hz^{2/3}$
Dp: equivalent diameter, mm	Ei: impact energy, j
Dh: harmonic mean diameter, mm	Tss: Total soluble solids
Sa: surface area, mm^2	β: Release angle of pendulum
Ra: aspect ratio	α: Return angle of pendulum

MATERIALS AND METHODS

To conduct test procedure tomato samples were provided from a research station of faculty of agriculture located at the country of Tabriz in the East Azerbaijan province, Iran in 2015. The samples were at the medium and relatively maturity conditions and having three sizes small, medium and large. The total of samples wrapped into the cloth and placed in the box and transported to the engineering properties of biological material laboratory of University of Tabriz, based on the experimental design (factorial) labeled and placed in the incubator with temperature and humidity of 4°C and 85 percent respectively. Therefore bruising model parameters and some additional parameters were calculated as the following procedure.

A. Determination of Physical properties

The physical properties in this research were fruit dimensions (L, W, T), mass (M), volume(V), sphericity (ϕ), arithmetic mean diameter (D_a), geometric mean diameter (D_g), equivalent diameter (D_p), harmonic mean diameter (D_h), surface area (S_a), aspect ratio (R_a), radius of curvature(R*), specific gravity(S_g) and Moisture content (M_{wb}).

Size, mass and volume measurements and calculation of some physical parameters. The principal dimensions (L, W, and T according to fig. 1) were measured by a digital caliper (1Mitutoyo, Japan accuracy of 0.01 mm). To obtain the mass each tomato was weighed on a precision electronic balance (accuracy of 0.01 g). True volume was determined using platform scale (Mohsenin, 1986). The tomatoes were coated with a very thin layer of epoxy resin adhesive (Araldite) in order to avoid adsorption of water during the experiment. The adhesive is found to be insoluble in water, resistant to heat and humidity and the increase in weight of the material due to the adhesive coating was negligible (less than 0.5 %) (Vilche, Gely *et al.,* 2003). After determining mentioned parameters the following formulas used for calculating some of physical parameters (Mohsenin, 1986, Aydin and Özcan, 2002, Olaniyan and Oje, 2002, Oyelade, Odugbenro *et al.*, 2005, Coskun, Yalçin et *al.*, 2006, Singh and Reddy, 2006, Hacıseferoğulları, Gezer *et al.*, 2007, Owolarafe, Olabige *et al.*, 2007, Li, Li *et al.*, 2011).

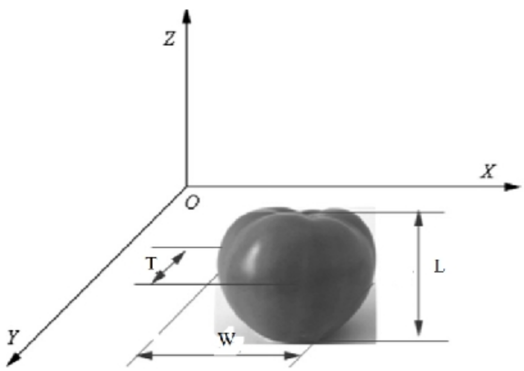

Fig. 1. Three major dimensions of tomato fruit ((Li, Li *et al.,* 2011).

$$D = \frac{(LWT)^{\frac{1}{3}}}{L} \times 100$$

$$Ra = \frac{W}{L} \times 100$$

$$S_g = M/V$$

$$D_a = \frac{L+W+T}{3}$$

$$D_p = \left[L * \frac{(W+T)^2}{4}\right]^{1/3}$$

$$Dg = (LWT)^{\frac{1}{3}}$$

$$D_h = \pi r^2$$

$$D_p = \pi r^2$$

$$S_a = \frac{\pi B L^2}{2L-B},$$

Where $B = (WT)^{\frac{1}{2}}$

Moisture content. The moisture content of a fruit specifies the water content exists in the wet sample which is one of the effective factors that affects the total properties of the product. Generally there are two methods for determining the moisture content of a product; wet and dry based. In this study wet based method was used and the following formula was exerted to calculate the moisture content (Sacilik, Keskin *et al.,* 2006).

$$M_{wb} = \frac{m_1 - m_2}{m_1} * 100$$

Where m_1 weight of sample and m_2 weight of dried sample.

In order to determine this parameter a number of samples sliced and placed into the oven at the temperature of 70°C for 72 hours as far as weight reduction didn't observe.

Radius of curvature and harmonic radius of curvature. The radius of curvature was calculated using equation described by Mohsenin (1986). Because tomatoes are not perfect spheres, the harmonic average (R*) was calculate based on the circumferential (R_1) and Meridian radius of curvature (R_2). The harmonic average was preferred over arithmetic average, because it privileges the smaller radius of curvature(Michael Van Zeebroeck, Darius *et al.,* 2007, M. Van Zeebroeck, Van linden *et al.,* 2007) which contributes more to the peak contact pressure (Hertz theory).

$$EL = \frac{PF}{t}$$

B. Determination of some mechanical properties

The mechanical properties that were considered in this research were contact peak force (PF), contact time (t), Elast (EL), restitution coefficient (R_c), acoustic firmness (S), impact energy (E_i).

Experimental setup. The contact force is one of the important parameters which contribute in the bruising models so that bruising models are established on the contact peak force and absorbed energy in the impact phenomenon(Van linden, De Ketelaere *et al.,* 2006, Michael Van Zeebroeck, Darius *et al.,* 2007). An instrumented pendulum was used to apply controlled impact energy to the fruit. The device was developed at the laboratory (Biophysics and mechanical properties of agricultural products laboratory, University of Tabriz, Iran). The pendulum consists of fixed metal construction to which a rotating wooden arm with a length of 0.45 m is attached. At the top end of the arm is the pivot. The bearings of the pivot were mounted on the frame to be produced the least possible friction during the motion of the arm and at the lower end of the pendulum arm sits an aluminum impactor of spherical shape with the tip of 25 mm radius of curvature that best approximates the shape of a tomato fruit and also impact or was equipped with force sensor (PCB piezotronics, sensitivity of 10.71 mv/N) and an accelerometer (PCB piezotronics, sensitivity of 100.5 mV/g). The data signals collected by a DSA (Dynamic Signal Analyzer, Econ Electronics Co. China). The tomato was placed on the adjustable table and embedded in foam rubber to be hold tightly. The foam rubber serves as an infinite contact plane between the sample and the sample holder at the opposite side of sample where the impact occurs.

Hence, the loss of impact energy at this spot 1800 apart from the impact location is assumed to be zero. The tomatoes are positioned such that the contact angle between the fruit surface and the pendulum impactor equals zero when the arm is at its lowest point (in rest). The tomatoes were impacted one, two and three times at three levels of energy0.125, 0.25 and 0.5 J to study the tomato texture behavior. Then the contact force can be easily measured by conducting the experiments.

Elast. It is a new parameter which was introduced to show the elasticity of tomato and is determined by the following formula (Van linden, Scheerlinck *et al.*, 2006)

$$EL = \frac{PF}{t}$$

Rebound coefficient (coefficient of restitution). The capacity of a material for storage of strain energy in the elastic range. From of other point of view it can be said that the coefficient of restitution is also a measure of energy recovery. The restitution coefficient is a measure for the damping characteristics of the fruit it can be obtained by the following formula (Mohsenin, 1986):

$$R_c = \frac{Sin(\frac{\alpha}{2})}{Sin(\frac{\beta}{2})}$$

Acoustic firmness. The firmness of tomatoes was monitored with the acoustic impulse-respond method. The tomato was placed with the stalk sideways on asupport covered with foam rubber (Schotte, De Belie *et al.*, 1999). In this support at a few mm from the fruit surface, an upward directed microphone (PCB, HT426E01 ICP, sensitivity 45.41 mV/Pa, USA) was mounted. The tomato was excited by gently impacting it on the equator at the opposite side of the microphone with a solid plastic rod. A Fast Fourier Transformation was performed by using Matlab software. In the resulting frequency spectrum, the first resonance frequency was selected (De Baerdemaeker, Lemaitre *et al.*, 1982, Huarng, Chen *et al.*, 1993). Fig. 2 shows a typical frequency spectrum for a tomato and the selected peak.

$$S = f^2 . m^{\frac{2}{3}}$$

Where f is the first resonance frequency (H_z), and M is the fruit mass (g).

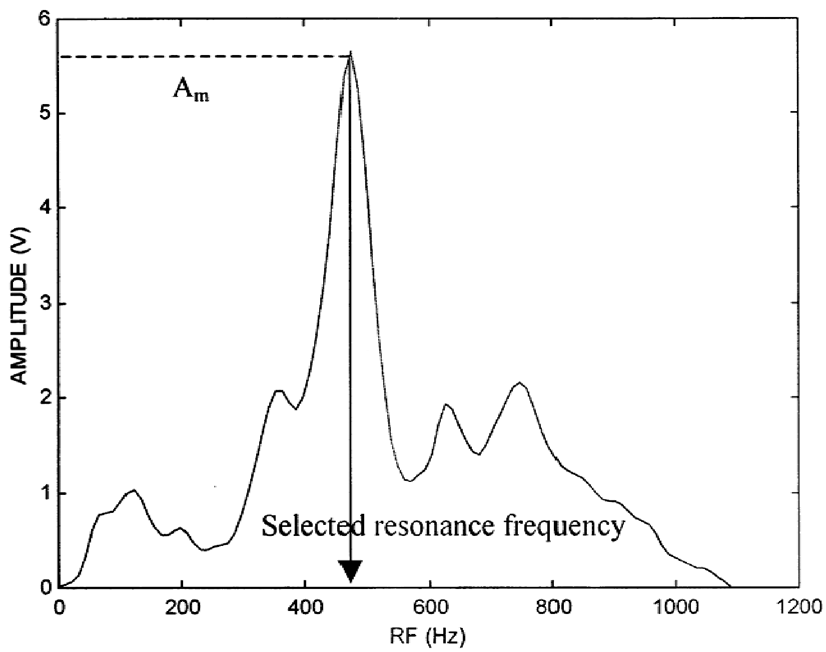

Fig. 2. Typical frequency spectrum for a tomato (Schotte, De Belie *et al.*, 1999).

C. Chemical properties

The chemical properties in this research were total soluble solids (TSS) and titratable acidity (TA). The TSS and TA were determined by hand held Brix Refractometer (model RHB 0-80, China) and AOAC method respectively (AOAC, 1984, Özcan and Aydin, 2004).

D. Statistical analysis

All tests were repeated at least three times and results and the means and standard deviations calculated. Measurements were compared using SPSS software. Factors included impact energy level (with levels of 0.125, 0.25 and 0.5 J) and numbers of impacts (1, 2 or 3).

RESULTS AND DISCUSSIONS

A. Physical and chemical properties

A summary of the results of the determined physical parameters is shown in Table 1. The mean length, width and thickness were found to be 61.92, 53.86 and 53.44 mm respectively. The importance of obtaining these parameters can be used in determining aperture size of machines, particular in separation of materials and manufacturing boxes for handling and transporting to be reduced mechanical damage.

Table 1: Some physical, mechanical and chemical properties of tomato.

Properties	Mean	Standard Deviation	Minimum	Maximum
L, mm	61.9271	6.07049	40.73	76.10
W, mm	53.8602	7.23361	39.30	72.15
T, mm	53.4481	6.64580	40.79	67.58
M, gr	100.7838	32.02384	48.15	167.56
ϕ (%)	0.9084	0.05544	0.80	1.06
D_a, mm	56.4118	6.17086	43.28	68.55
D_g, mm	56.2226	6.22715	43.24	68.35
D_h, ,mm	56.0424	6.28185	43.20	68.16
D_p, mm	56.2308	6.23158	43.24	68.35
Sa, mm^2	10050.6809	2196.67476	5873.46	14677.33
R_a	0.8702	0.08439	0.71	1.11
Mwb, (%)	65.9073	19.44591	23.98	90.49
R^*,mm	36.5213	6.97109	25.37	60.68
V, cm^3	98.9663	32.08186	46.75	167.55
S_g, gr/cm^3	1.0223	0.05701	0.59	1.16
S, $10^6m^2Hz^{2/3}$	8.84	1.29	6.64	10.64
TSS	3.58	1.03	1.5	5.9
TA	4.00	0.49	3.4	5.25

The average fruit mass was about 100.78 gr. The specific gravity was about 1.02 gr/cm^3. It can be said that the higher specific gravity in comparison with water (1 g/cm^3) causes a tendency for the tomato fruit to sink in a water. These properties may be useful in the separation and transportation of the fruit by the hydrodynamic means (Owolarafe and Shotonde, 2004). The specific gravity play a relatively important role in the bruising model because by increasing this value the initial forces against impact forces may be varied.

The sphericity and aspect ratio were found to be 90.84 and 87.02 percent, respectively. The high sphericity of tomato fruit is indicative of the tendency of the shape towards a sphere. Taken along with the high aspect ratio of 87.02 % (which relates the fruit width to length), it may be deduced that the tomato fruit will rather roll than slide on their flat surfaces. However, the aspect ratio value is being close to the sphericity values may also mean the tomato fruit will undergo a combination of rolling and sliding action on their surfaces (Omobuwajo, Sanni *et al.*, 2000, Oyelade, Odugbenro *et al.*, 2005).

The maximum and minimum value of TSS were about 3.4 and 5.25 with coefficient variation of 28.74 percent shows that the selected samples for this experiment were at premature to mature stage of maturity.

B. Mechanical properties

As shown in Table 1, the average of acoustic firmness of tomato was 8.84 ($10^6m^2Hz^{2/3}$). Similar results have also been reported by Van linden, De Ketelaere *et al.* (2006). Schotte, De Belie et al. (1999) reported that the tomatoes with a stiffness of 2.0 ($10^6m^2Hz^{2/3}$) or less had more than 50% chance of being rejected by experts. They also mentioned that experts considered tomatoes with a stiffness factor of less than 3 ($10^6m^2Hz^{2/3}$) to be too soft. It indicates that the studied tomatoes were relatively firm and resistant to mechanical damage.

Table 2 shows the results of conducted tests related to some impact parameters obtained from a pendulum experiments. Obviously, restitution coefficient as well as PF increased with the intensity of the applied impact According to the table 2, at three impact energy levels, by increasing the number of impacts at one point, the related contact peak force of tomatoes was increased.

The mean restitution coefficient values for 0.125, 0.25 and 0.5 J energy levels were about 0.2507, 0.2928 and 0.2849 respectively, so the restitution coefficient values were the highest for medium impacts and the lowest for lowest impacts. These results coincides with obtained conclusions by Van linden, De Ketelaere *et al.* (2006). It can be said that by increasing the value of rebound coefficient, the risk of bruising is decreased.

As shown in Table 2, the minimum contact time observed at third impact energy level with impact number 3 while the highest belonged to second energy level with impact number 1.

Table 2: Impact parameters obtained from a pendulum experiment for three different impact energy levels at one, two three times impacted tomato.

Energy levels, J	Number of impacts	PF,N	t, s	R_c, dimensionless	EL, N/S
E_1=0.125	1	26.89	0.0159	0.2234	1730.52
	2	31.81	0.0146	0.2740	2837.72
	3	32.31	0.0156	0.2860	2122.10
E_2=0. 25	1	35.70	0.0165	0.2679	2200.43
	2	42.23	0.0155	0.3157	2767.28
	3	41.50	0.0160	0.3217	2655.18
E_3=0.5	1	55.06	0.0154	0.2671	3653.60
	2	65.34	0.0147	0.3020	4522.57
	3	69.15	0.0144	0.3043	4936.12

CONCLUSION

These data will have a potential to apply in harvest, transportation, classification, processing, sorting, packaging and other processes operations related to this variety. Also these findings can be used in the bruising models to predict the amounts of mechanical damage and development of harvest and postharvest chain machines.

In summary, it can be said that this variety of tomato with specific gravity larger that water, the hydrodynamic system could not be used in handling at processing plants. As mentioned before, the higher aspect ratio may be used in designing of handling systems, the rolling action should be considered. According to the obtained results it can be concluded that in designing machines in mechanized operations the impact energy level excreted to products must be diminished.

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